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Diurnal and seasonal dynamics of soil respiration in desert shrubland of *Artemisia Ordosica* on Ordos Plateau of Inner Mongolia, China

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Abstract: The diurnal and seasonal dynamics of soil respiration in the *A. ordosica* shrubland on Ordos Plateau were investigated in the growing season (May-October) of 2006 and their environmental driving factors were also analyzed. Results indicated that diurnal dynamics of soil respiration rate and its temperature dependence showed some discrepancy in two different growth stages (the vegetative growth stage and the reproductive growth stage). During the vegetative growth stage, the diurnal variation of soil respiration was slight and not correlated with the daily temperature change, but during the reproductive growth stage, the daily respiration variation was relatively large and significantly correlated with the diurnal variation of air and soil temperature. In the growing season, the peak value of soil respiration occurred at July and August because of the better soil water-heat conditions and their optimal deployment in this period. In the shrubland ecosystem, precipitation was the switch of soil respiration pulses and can greatly increase soil respiration rates after soil rewetting. Moreover, the soil respiration rates in the growing season and the air temperature and soil surface water content were closely correlated ($p<0.05$) each other. The stepwise regression model indicated that the variation of soil surface moisture accounted for 41.9% of the variation in soil respiration ($p<0.05$).

Keywords: Soil respiration; Shrubland; *Artemisia ordosica*; Ordos Plateau

Introduction

Grasslands, covering nearly one-fifth of the world's land surface area, are one of the most widespread vegetation types worldwide (Lieth 1978) and play a significant role in the global carbon cycle (Hall *et al*. 1995; Scurlock *et al*. 1998). However, a large area of grasslands in the world has been faced with a serious problem-degradation and desertification. One form of desertification is the conversion of homogeneous grasslands into shrub-dominated ecosystems and such conversion has been noted over wide areas in the world (Grover *et al.* 1990; Schlesinger *et al*. 1990; Archer *et al*. 2001; Huenneke *et al*. 2002). The change of plant type and coverage from grasslands to shrublands has greatly affected ecosystem function and biogeochemistry cycles, including the carbon cycle (Schlesinger *et al*. 1998; Huenneke *et al*. 2002; Jackson *et al*. 2002; Asner *et al*. 2003; Scott *et al*. 2006). Soil respiration, the emission of CO_2 from soil surface, is the primary path of ecosystem carbon cycle and partly controls the potential of ecosystem carbon sink. But until now, there are rarely little reports about soil respiration over these transitional areas. In northwest of China, most of grasslands have been affected by desertification (China National Committee for the Implementation of the UN Convention to Combat Desertification, 1992) and shrub invasion is also very popular (Xiong *et al*., 2005). Although the shrub-dominated ecosystems indicate one form of grassland degradation and desertification, the shrublands also play a critical role in combating desertification and promoting the built-up of plants in deserts (Li 2005). To date, reports on soil respiration of grasslands in China mainly focus upon temperate grassland representative of in Inner Mongolia and the Songnen Plain (Dong *et al*. 2000; Dong *et al*. 2005; Qi *et al*. 2007), and alpine grasslands on Qinghai-Tibetan plateau (Du *et al*. 2006; Zhao *et al*. 2006), rare are reports about soil respiration of shrublands in desert ecosystems. Therefore, reinforcing research on soil respiration and carbon sequestration of such grassland biome is crucial for accurately predicting the potential carbon sink of terrestrial ecosystems in China.

In this paper, in situ soil respiration of desert shrubland of *A. ordosica* was measured in Mu Us sandy land on Ordos Plateau of Inner Mongolia, China. The questions addressed were: (1) Characteristics of diurnal and seasonal dynamics of soil respiration; (2) effect of temperature, soil water and precipitation on diurnal and seasonal dynamics of soil respiration.

Materials and method

Site description

The experimental sites were situated in the Mu Us sandy land on

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Ordos Plateau of Inner Mongolia, China (39° 29′ N, 110° 11′ E, 1335 m above sea level) and in the vicinity of Ordos Sandy Grassland Research Station, which belongs to the Chinese Terrestrial Ecosystem Flux Observational Network. The site is at the ecotone between grassland and shrubland where the desertification is serious. The climate is a typical semiarid continental climate with remarkable seasonal and diurnal temperature variation and low rainfall. Annual mean precipitation is 345.2 mm with annual mean evaporation (2535 mm). The mean precipitation from April to October is 321.8 mm, which accounts for about 93% of annual precipitation. Annual mean temperature is 6.7ºC and the monthly mean temperatures are below 5ºC from November to March, and between 7.4 and 21.9ºC from April to October (Zheng *et al*. 2005). The shrub community is dominated by *A. ordosica*. Besides, *Hedysarum fruticosum*, *Pennisetum centrasiaticum*, *Agropyron desertorum*, *Agropyron fragile*, *Oxytropis psammocharis*, *Astragalus melilotoides* etc. also coexist in the shrub community.

Gas sampling

CO_2 gas samples were mainly collected through a static closed opaque chamber in the growing season (May-October) of 2006. In opaque sampling chamber, the influence of plant photosynthesis and the shortcoming of overly rapid rising temperature can be eliminated during the measurements. The effectiveness of the static opaque chamber method in measuring CO_2 efflux was reported by some scholars (Dong *et al*. 2000; Zou *et al*. 2004). In this study, the static closed opaque chamber was made of 8-mm thick black acrylic material with a tinfoil reflecting film attached to the external surface. The geometric size of the chamber was in 50 cm (length) × 50 cm (width) × 40 cm (height). Because plant cover is greatly patchy in the shrub community, three treatments were made, including bare and covering biologic crusts soil in interplant spaces and soil beneath shrubs (above-ground vegetation was cut to ground level 1 day before the sampling). Moreover, each treatment was set two duplications and the average results of measurements were taken in order to reduce the experimental errors resulting from the spatial variation of CO_2 emissions. The gases were collected in first week and third week of each month from May to October. The samplings were done at the relatively uniform time, mostly at 09:00–11:00 in the morning because effluxes measured during this time are regarded to be basically representative for the daily average flux (Kessavalou *et al*.1998; Du *et al*. 2006). In addition, two observations on daily variations were carried out in the vegetative growth stage and the reproductive growth stage during the experimental period. Gas sample gathering for daily variation studies began normally at 07:00 in the morning and ended at 07:00 next morning. One group of the samples was gathered once every three hours.

During the course of measurements, the sampling chamber was put into a groove of a stainless steel frame and sealed with distilled water, and the stainless steel frame was inserted 5 cm into the soil. The lid of the chamber was installed with a fan driven by a 12 V lead-acid battery which circulated air, a highly precise temperature sensor connected with a digital thermometer, as well as a gas channel being constituted of a PVC tube, a silica gel pipe connected to a 200-mL syringe and a three-way stopcock for gathering gas. Gas sampling lasted 30 min, and gas samples were extracted from the chamber at 0, 10, 20 and 30 min respectively after capping. Each time, about 200 mL of gas was extracted from the chamber and collected in polyethylene-coated aluminum gas bags; CO_2 concentrations were measured in the laboratory shortly after the sampling by a LI-6252 infrared CO_2 analyzer (LICOR Inc., Lincoln, N E, U. S. A).

Temperature and soil water content measurement

During each gas sampling, air temperature, soil temperatures (at depths of 0 cm, 5 cm and 10 cm), soil water content, and the internal temperature of the chamber were gathered simultaneously. Temperature in the chamber was measured with a temperature sensor, air temperature was measured with a DHM2 mechanical ventilated thermometer, and soil temperatures at depths of 0, 5 and 10 cm was measured with a SN2202 digital thermo detector produced by the Sinan Instruments Plant of Beijing Normal University. To determine soil water content, an oven-drying method was used.

Data analysis

The method used to calculate CO_2 effluxes has been described by Dong *et al*. (2003) and the statistical analyses (multiple stepwise regressions) were made by SPSS 11.0 (SPSS Inc., 2001). Graphs were prepared by using Excel (Microsoft Corp., 2003) and Coreldraw 12.0 (Corel Corp. 2003).

Results

Diurnal dynamics of soil respiration

Diurnal dynamics of soil respiration was investigated twice on June 21 and August 29, 2006, respectively in vegetative growth stage and reproductive growth stage of *A. ordosica* (Fig. 1). During the vegetative growth stage, diurnal variation of soil respiration was slight and daily average CO_2 efflux was 37.27 $mg{\cdot}m^{-2}{\cdot}h^{-1}$. The peak value (50.64 $mg{\cdot}m^{-2}{\cdot}h^{-1}$) occurred at around 13:00 at noon. After that, soil respiration rate decreased gradually, reaching the minimum value (20.65 $mg{\cdot}m^{-2}{\cdot}h^{-1}$) at 22:00 in the evening. During the reproductive growth stage, there existed relatively great diurnal variation of soil respiration with the daily average CO_2 efflux (79.17$mg{\cdot}m^{-2}{\cdot}h^{-1}$). The maximum and minimum value of soil respiration, 147.94 $mg{\cdot}m^{-2}{\cdot}h^{-1}$ and 23.99 $mg{\cdot}m^{-2}{\cdot}h^{-1}$ respectively, appeared at 13:00 at noon and at 01:00 in the morning.

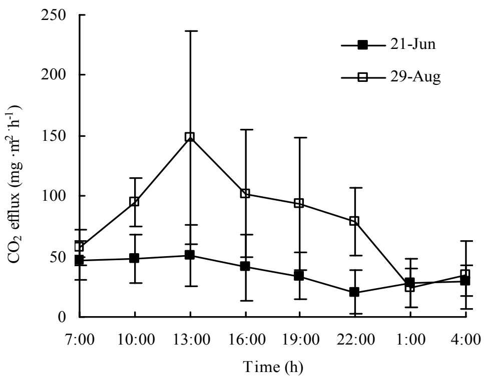

Fig. 1 Diurnal dynamics of soil respiration in the shrubland of *Artemisia.ordosica*

Seasonal dynamics of soil respiration

Soil respiration showed obvious seasonal dynamics in the growing season (Fig. 2). In late spring and early summer, soil CO_2 efflux stayed at a low level, then increased quickly with time, reaching higher emission value in July and August and began to decrease from early September. The seasonal characteristic of soil respiration indicates that temperature and soil water condition play an important role in regulating ecosystem function and biogeochemistry cycle in desert shrublands. In the experiment site, most of precipitation in a year occurred at July and August. Moderate temperatures and adequate soil moistures during July and August triggered ecosystem functioning, particularly plant growth and soil microbial activity, with higher soil respiration and soil crust formation observed during this period.

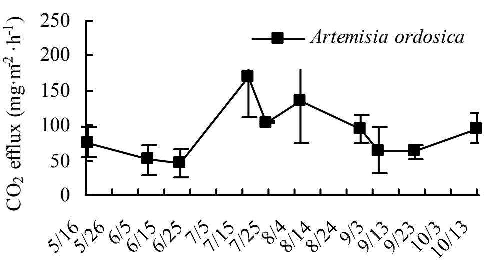

Fig. 2 Seasonal dynamics of soil respiration in the shrubland of *Artemisia ordosica* in 2006

Effects of temperature and soil surface water on soil respiration

Temperature dependence of diurnal dynamics of soil respiration also showed some difference in two different growth stages (Table 1). During the vegetative growth stage, the diurnal variation of soil respiration showed no significant correlation with daily variation of temperature change, but during the reproductive growth stage, diurnal dynamics of soil respiration was closely correlated to the daily temperature variation ($p<0.05$). For seasonal dynamics of soil respiration, it was controlled by both temperature and soil surface water content and was significantly correlated with variations of air temperature, inner-chamber air temperature and soil water content at a soil depth of 0-10 cm ($p<0.05$), (Table 2).

Table 1. Correlations of temperature change with diurnal soil CO_2 flux rates

Time	Air temp.	Inter-chamber temp.	Soil surface temp.	5-cm soil below-ground temp.	10-cm soil below-ground temp.
21 Jun	0.68	0.64	0.60	0.30	0.02
29 Aug	0.88^{**}	0.89^{**}	0.89^{**}	0.83^{*}	0.74^{*}

Notes: **---- Correlation is significant at the 0.01 level (two-tailed). *---- Correlation is significant at the 0.05 level (two-tailed).

Table 2. Correlations of environmental factors with soil CO_2 flux rates and related linear stepwise regression equation

Correlations						
Air temp.	Inter-chamber temp.	Soil surface temp.	5-cm soil temp.	10-cm soil temp.	0-10cm SWC	10-20cm SWC
0.62^{*}	0.62*	0.16	0.23	0.17	0.65^{*}	0.44
Stepwise regression model						
Y=30.403 X_1 -5.653				F	a	R^2
				7.198	0.023	0.419

Notes: SWC means soil water content. **---- Correlation is significant at the 0.01 level (two-tailed). *---- Correlation is significant at the 0.05 level (two-tailed). X_1 is (at the soil depth of 0-10 cm) soil water content (%); Y is soil respiration rate (mg m^{-2} h^{-1}); a is the significance level of F-test; R^2 denotes the goodness of fit of the regression equation.

Discussion

At present, many reports about diurnal variations of soil CO_2 efflux in temperate grasslands have been published (Dong *et al*. 2000;Wang *et al*. 2002; Qi *et al*. 2005), but rare are reports about desert shrubland ecosystems. Dong *et al*. (2000) reported that diurnal soil CO_2 efflux was higher at daytime and lower at nighttime in temperate typical grassland in Inner Mongolia, China, and the peak value occurred at noon of 12:00 as well as the lowest value occurred at 03:00 in the morning. The daily average efflux was 1018.3 mg·m^{-2}·h^{-1}. In this paper, the shrub community of *A. ordosica* showed the same characteristics as Dong *et al*. measured, but the daily average efflux was far lower than that investigated by Dong *et al*. The difference may be attributed to the different soil organic matter level and precipitation amount. In the desert shrubland of *A. ordosica*, soil organic matter (SOC) is poor because of serious desertification (the mean SOC of the growing season is lower than 0.46%). Poor soil organic carbon and nitrogen accompanying with low precipitation resulted in lower soil respiration. On the contrary, the site investigated by Dong *et al*. was typical temperate grassland and the content of soil organic matter was much higher than that of the present study. Moreover, the daily mean CO_2 effluxes of Dong *et al*. were the results measured only in rainy season of typical temperate grassland when the water condition was much better than that of the period we measured.

Until now, although a lot of researches have been done on the effect of water-heat factors on soil respiration (Kirschbaum 1995; Davidson *et al*. 1998; Fang and Moncrieff 2001; Fang *et al*. 2005), we are still lack of enough information about the inner-mechanism of soil respiration in different terrestrial ecosystems. In this paper, temperature dependence of soil respiration was different in two stages of plant growth, and the difference was probably attributed to the confounded functions of water-heat factors. Li *et al*. (2000) reported that when air temperature was below 15ºC, seasonal dynamics of soil respiration of *Leymus chinense* steppe was extremely correlated with air temperature change and the effect of temperature was far higher than

that of soil moisture in this period. But when air temperature was above 15ºC, the temperature dependence decreased and soil respiration was controlled by both air temperature and soil moisture. In the present study, the daily air temperature was all above 15 ºC on June 21 and the soil water contents at soil depth of 0–10 and 10–20 cm belowground were 8.75% and 5.67% respectively. In contrast, the air temperature was very low in midnight and early morning on August 29 and the soil water contents at 0–10 and 10-20 cm belowground were 2.98% and 3.89%. According to the different water-heat conditions in the two sampling days, we can conclude that the temperature dependence of soil respiration may be low during the vegetative growth stage because of the higher daily air temperature and suitable soil moisture and the single factor of temperature or soil moisture can't remarkably affect the soil respiration in this period of time. But during the plant reproductive growth stage, air temperature in midnight and early morning was low and the temperature dependence of soil respiration was high. Moreover, soil surface moisture was poor in this period of time and hence the dynamics of soil respiration was mostly controlled by the temperature change.

Currently, there are still some difficulties in directly measuring regional CO_2 efflux accurately for a large-scale carbon cycle study, and therefore we usually make use of models to calculate and predict the value of regional soil respiration, of which soil water and temperature are the most basic parameters and are crucial to predict the potential response of soil respiration to future climate change. In present study, the authors built up statistical prediction model on soil CO_2 efflux by using the data measured in the growing season (Table 2). According to the model, the changes of soil water content at soil depth of 0-10cm accounted for 41.9% variation of soil respiration in the whole growing season (p<0.05).

Based on the data investigated in the growing season (Fig. 2), the authors also estimated the total soil respiration amount of growing season in the shrubland using integral quadrature between dynamic curves of the CO_2 efflux of the time interval and time axis and the value was 315.33 g·m^{-2}. In fact, it is very difficult to accurately estimate the amount of soil CO_2 efflux because of precipitation pulses in dryland ecosystems. Although many researchers estimated the amounts of soil carbon effluxes in semi-arid or arid regions, all these results didn't take the precipitation pulses into account. Presently, many ecologists used models to estimate carbon release in drylands, but there are still many puzzles in improving model accuracy (Reynolds *et al*. 2004; Ogle *et al*. 2004). In the present study, the authors observed soil respiration pulses after two large rainfall events and found precipitation greatly increased the intensity of soil respiration (Fig. 3). According to Fig. 3, authors added the carbon release triggered by precipitation pulses to the amount of CO_2 efflux measured normally in the growing season, and the total CO_2 emission value of growing season was 438.95 g·m^{-2}, which was much higher than 315.33 g·m^{-2} estimated using the data of Fig. 2. The result indicates that precipitation pulses have profound effect on estimation of soil respiration, especially in semi-arid and arid ecosystems, where the soil respiration is usually weak because of low precipitation and soil organic carbon as well as nitrogen contents. In desert ecosystems, precipitation is the switch of soil respiration pulses and soil carbon emission rate can increase by 30 times immediately after soil rewetting (Sponseller 2007). Continuous measurement of soil respiration in field is the best way to accurately estimate the amount of soil carbon release, but we generally can't achieve the target because of big workload. Additionally, precipitation pulse is a complicated process and shows different responses to storm size and time (Austin *et al*. 2004). Therefore, simulated experiment in laboratory would perhaps be a good way to solve the problem.

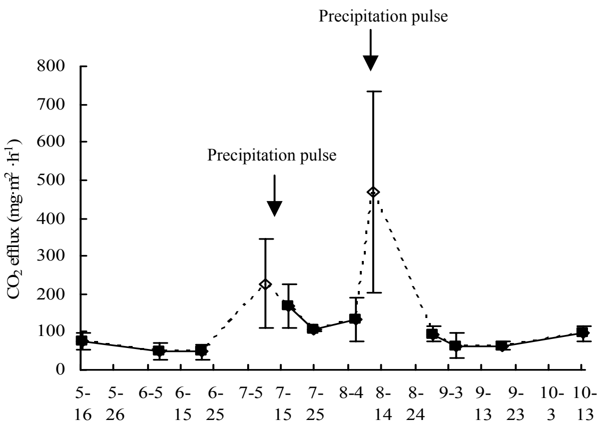

Fig. 3 Dynamic change of soil respiration with two times of precipitation pulses in the growing season.

Solid line indicates seasonal dynamics of soil respiration with normal observation, dotted line indicates soil respiration pulses after two times of large rainfall events

Conclusions

Diurnal dynamics of soil respiration and its temperature dependence in the desert shrubland of *A.ordosica* showed some discrepancy in two different growth stages. During the vegetative growth stage, daily average soil CO_2 efflux was 37.27 mg·m^{-2}·h^{-1} and diurnal dynamics of soil CO_2 efflux wasn't correlated with daily variations of air and soil temperature; but during the reproductive growth stage, daily average soil CO_2 efflux was 79.17 mg·m^{-2}·h^{-1} and diurnal variation of soil CO_2 efflux was significantly related to the daily variations of air temperature, inner-chamber temperature and soil temperature at soil depth of 0–10 cm (p<0.05). There existed obvious seasonal dynamics of soil CO_2 efflux in the growing season and the peak value of CO_2 efflux occurred in July and August. Suitable temperature and soil water condition are the major drive force of soil respiration booming. In the desert shrubland, soil respiration can be strongly stimulated by precipitation and the precipitation pulses would have a profound influence on the estimation of total soil CO_2 efflux. In the growing season, soil respiration was controlled by soil surface water content and the variation of soil surface moisture accounted for 41.9% of the variation in soil respiration (p<0.05).

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